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Analyzing the Greek renewable energy sector: A Data Envelopment Analysis approach

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ABSTRACT

This paper applies a bootstrapped Data Envelopment Analysis (DEA) formulation aiming to evaluate the financial performance of the firms operating in the Greek renewable energy sector. With the use of financial ratios in a DEA setting, efficiency ratios are constructed in order to analyse firms' financial performance. The results reveal that firms' performances are positively influenced by the high levels of return on assets and equity and by lower levels of debt to equity. In addition it appears that there are not significant differences of firms' efficiency levels indicating high competitiveness between firms. Finally, firms producing wind energy appear to perform better than firms producing hydropower energy. It emerges that the majority of firms are operating in the wind and hydropower energy production making the Greek market of solar energy production being an emerging segment of the Greek renewable energy sector.

Contents

1. Introduction

The increase in world population demands a successful implementation of sustainable development. Nowadays conventional energy sources satisfy the majority of the world energy demand. However renewable energy sources (like solar, hydropower, wind and biomass) are the main environmental friendly alternatives [1]. Changes towards more environmental friendly energy sources will not only deter environmental degradation but they are undepleted, more flexible, and give the possibility of decentralization [2]. As the world becomes more sensitive to environmental issues, countries with obsolete energy sectors, like Greece, will be forced to make radical changes.

The Kyoto protocol is a product of this environmental sensitivity. According to the protocol, countries must limit the growth of Greenhouse Gases (GHGs) to 25% and the production of renewable energy sources (hereafter RES) must be the 20% of the total energy production [3]. Agoris et al. [4] examine three different scenarios for three different energy policies under the Kyoto framework. They conclude that if the Greek government makes the proper investments, the Kyoto targets may be achieved for Greece.

Banõs et al. [5] suggest that governments and businesses strangle on the decision of whether or not to establish renewable energy systems in a given place, but they fail to decide which renewable energy source or combination of sources is the best for each place. Based on that dilemma Evans et al. [6] concluded that wind power can require more land and high relative capital costs but has the lowest relative greenhouse gas emissions and the least water consumption demands.[1]

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[1] For recent studies investigating the impact of renewable energy systems on Economics and the environment see also Hepbasli [7] and Varun Prakash and Bhatt [8].

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Several industry studies have shown the importance of renewable energy sources and especially for solar energy which can be viable alternative source of industrial energy. However according to Taibi et al. even though solar heating can reduce costs in industries, not much attention has been received from industry policy makers [9]. Moreover, Ibrahim [10] examined the Egyptian electricity market and found that solar and wind energy will be the main driving forces of Egypt's electricity generation. Trappey et al. [11] by applying systems dynamic models illustrated that for the case of the Taiwan Penghu island the dynamic effects of solar energy can be a viable solution to energy related problems also for other regions. Furthermore, for the case of India Sharma et al. [12] have found that renewable energy sources are the main solution to India's long-standing energy problems. Especially they claim that solar energy can increase energy security, reform and 'open' the renewable market and address India's environmental concerns.

However the adoption and implementation of RES is not a straightforward scenario for some countries. Hamed Abu et al. [13] suggest that due to different conditions (infrastructural, political, social, geographical, economic and environmental) of the Palestinian Territories it is very difficult to use RES which in turn could replace more than 25% of the current demand of the Palestinian energy.

Furthermore, in the case of Greece Kaldellis et al. [14] argue that the final cost of locally produced water from RES in Greek islands is significantly lower than the cost of transferred water. Doukas et al. [15] investigate the sustainable electricity technologies in Greece and find that from environmental friendly energy sources, wind and biomass are of extreme interest. According to Diakoulaki and Karangelis [16] higher penetration of renewable energy sources is the best compromised configuration for the Greek power generation sector.

Diachronically, Greek electricity market is controlled either directly or indirectly by the state. A thorough historical background of Greek electricity sector is presented by Illiadou [17]. According to the author, at 1950 the state merged the small scattered local electricity enterprises into a large national company, the Public Power Corporation (PPC), which was a 100% public corporation. PPC was a monopoly as the Greek national law forbade any private energy enterprise. At 1994, private individuals were allowed for first time to produce power but only for their own use, for cogeneration with PPC and for RES. They were also obliged to sell to PPC the excessive amount of energy which they did not consume.

During the last decade, legal efforts have been made in order to comply with EU legislation and liberalize the energy market. Despite the efforts, PPC is still under public control and continues to possess almost the entire market of electricity production and provision. According to Illiadou [17], two significant issues of the Greek energy sector are the under-investment and the inability to produce power with modern techniques which are more efficient and less costly.

Within the EU, as the Greek energy sector is responsible for the majority of total CO_2 emissions, Greece must increase the restriction for GHG up to 25% between 2008 and 2012 [18]. As mentioned, the Greek electricity sector is obsolete. In 1999, 89.1% of the electricity was produced by fossil fuels, while from more friendly to the environment energy sources, only hydropower is worth mentioning with a 10.1% [19]. In mainland Greece, the situation is slightly better as the production of hydropower was 27% of the total energy production but on islands 93% of the total production came from heavy or light fuel oil [20].

On the consumption side, in 2006 68.5% of the final energy consumption came from oil and 21% from electricity, while only 5.2% came from RES [21]. Another interest aspect is that the vast majority of hydropower stations and wind power installations belong to PPC [19]. Many authors point out that the Greek electricity sector needs radical reform. Hondroyiannis et al. [22] study the relationship between energy consumption and economic growth over the period 1960–1996 and find that there is a strong relationship between them. Furthermore, they claim that structural changes in the Greek electricity sector will lead to rapid economic growth and that economic growth will lead to cleaner energy sources. Their results are in line with previous studies like Samouilidis and Mitropoulos [23], which indicate that structural changes are needed in the Greek electricity sector.

Based on these lines this paper by applying Data Envelopment Analysis (DEA) alongside with bootstrap techniques, analyses for the first time the Greek renewable energy sector by using financial data of 78 firms (this sample includes all the main/largest companies) operating in that sector for the period 2006–2008.

2. The theoretical background for measuring firms' financial performance

The assessment of a business unit's efficiency has attracted the interest worldwide. A simple approach to measure the efficiency is by using financial ratios which permit comparison of decision making units (DMUs) of different sizes [24]. A major drawback of this approach is that a single financial ratio does not incorporate every aspect of a unit's efficiency and thus it is not a sufficient measure. Moreover, if we examine more than one financial ratio, everyone is compared with a benchmark which is not similar for every single financial ratio. For example, if we examine the efficiency of a group of firms based on return on assets (ROA) and return on equity (ROE) it is possible that a firm which is marked as a benchmark based on ROA is not a benchmark based on ROE. Furthermore, when one makes the comparison based on a single financial ratio then it is assumed that every other factor is constant, which is a simplification of the truth [25].

In order to overcome those problems, an aggregation of financial ratios is necessary. Financial ratio analysis weights a number of single financial ratios into one combined ratio [26]. According to Yeh [25], aggregation of single financial ratios is not an easy task because of the changing economic conditions. The subjectivity of the aggregation is a significant disadvantage of this approach as it is based on imagination and experienced judgment [27]. Financial ratio analysis is used widely across the literature, applied in various sectors like banking [28], healthcare [29] and for business firms in general [30,31]. In other approaches, authors incorporate financial ratios in several analytical settings such as regression analysis [32], multi-discriminant models [33] and logistic and probabilistic regressions [34,35].

Berger and Humphrey [36] investigate a large number of studies and argue that frontier analysis is preferred to traditional ratio analysis as it determines objectively an overall efficiency value and provides a ranking for the units under assessment. There are two main frontier approaches, parametric and non-parametric analysis. Each of them has one significant disadvantage. Parametric analysis requires specification of the functional form while non-parametric analysis does not allow for an error term. The most remarkable non-parametric approach is the Data Envelopment Analysis applied in various sectors.

Traditionally, DEA uses absolute numbers as variables however in a number of special cases uses ratios instead [37]. These special cases may involve the nature of the accessible data or the need for a proper reflection of the production function. Emrouznejad and Amin [38] argue that standard DEA approach with ratios used as inputs or outputs may lead to incorrect result. The authors suggest a number of alternative DEA models in order to address the problem.

The sector with the majority of studies in the field is probably the banking sector. Yeh [25] investigates the efficiency of six banks in Taiwan over the period 1981–1989. A DEA model is adopted with

interest and non-interest expenses and total deposits as inputs and interest income, non-interest income and total loans as outputs. Then, the group is divided into 3 subgroups: low, medium and high efficiency banks. A number of 12 financial ratios are calculated in order to assess the various characteristics of each bank. The author underlines the significance of the DEA approach in the calculation of the overall efficiency.

Halkos and Salamouris [24] apply Lovell's [39] model at 50 commercial Greek Banks and they investigate the efficiency of Greek commercial banking system over the period 1997–1999. Lovell [39] uses standard macroeconomic measures and presents a modified DEA model in order to measure the overall efficiency. Halkos and Salamouris' [24] study differ from previous ones, by applying a DEA model with six outputs and no inputs. The authors justify the absence of inputs by pointing out that for banks which operate under the same market framework for money and services, all inputs are considered similar and equal. The outputs consist of six financial ratios: ROA, ROE, profit/loss per employee (P/L), efficiency ratio (EFF), net interest margin (NIM) and return difference of interest bearing assets (RDIBA). The results are in line with previous studies relative to the superiority of efficient frontier approach.

Oberholzer and Westhuizen [40] investigate the efficiency of ten regional offices of one of the largest banks in South Africa, using financial ratios analysis and DEA. In order to measure profitability, ROA and profit margin (PM) are adopted while to assess the creation of income another two financial ratios are used, income to staff cost and income to assets. The authors conclude that DEA should be used as a complementary to financial ratios approach.

Avrikan [41] examines the relationship between DEA super-efficiency measures and a number of significant financial ratios for Chinese banks. It is fount that the correlations between DEA estimates and financial ratios are relatively low implying that it is possible to identify inefficiencies that were not feasible to identify with financial ratio analysis. These findings confirm with previous studies in that DEA approach defines benchmarks in a more objective manner.

Apart from the banking sector, the combination of DEA and financial ratios is used in healthcare by Ozcan and McCue [26]. The authors construct an indicator (Financial Performance Index, FPI) to measure the financial performance of 170 hospitals in the USA. They apply a constant returns to scale (CRS) DEA model with FPI as the only input. In order to construct the FPI index, four financial ratios are used: ROA, operating cash flow (OCF), operating margin (OM) and total assets turnover (TATURN). The results show that FPI is an effective measure of overall efficiency.

Nikoomaram et al. [42] incorporate seven financial ratios in a DEA model to measure the efficiency of 24 metal industries in Tehran over the period 2003–2008. They adopt an input oriented CRS DEA model considering operating expenses and owner's equity as inputs and net earnings and OCF as outputs. Furthermore, a multivariate regression is applied to examine the relation between DEA results and financial ratios, ROA, OCF, return on investment (ROI), residual income (RI), returns on sale (ROS), earnings per share (EPS) and price to earnings ratio (P/E). The final results indicate that ROS, EPS and OCF have significant impact on the efficiency of the industries.

Halkos and Tzeremes [43] include financial ratios in a DEA model and evaluate the efficiency of 23 Greek manufacturing sectors. As noted above, several authors indicate that financial ratios may lead to biased DEA efficiency estimates. The authors apply sensitivity analysis and bootstrap techniques in order to correct the problem. They find that sensitivity analysis lead to biased results while bootstrap techniques significantly improve efficiency estimates.

DEA approach has been also used in the construction of various environmental performance indicators. Hu et al. [44] examine water efficiency in China. They create an index of a water adjustment ratio (WATR) by incorporating water as an input in the DEA model. Tsolas [45] applied DEA and bootstrapping techniques in order to evaluate the performance in mining operations. The author uses a mixed mine environmental performance indicator (MMEPI) constructed by a VRS DEA model.

Non-parametric approaches have been applied extensively in energy sector to measure the efficiency either of firms or entire economies. Bagdadioglu et al. [46] adopt a DEA model to assess the efficiency of public and private owned organizations of electricity distribution in Turkey. Estach et al. [47] study the efficiency of 12 electricity firms in Africa over the period 1998–2005. Specifically, they include in their analysis 12 operators which provide services in 12 different countries of the Southern Africa Pool. Chien and Hu [48] investigate the impact of renewable energy on the efficiency of 45 economies for the years 2001–2002. Honma and Hu [49] examine the regional energy efficiency in Japan using a quite extensive data set compiled by 47 firms over the period 1993–2003. They include 14 inputs, labor, private and public capital stock and 11 energy sources and GDP as an output. Finally, Halkos and Tzeremes [50] evaluate the impact of electricity generation on the economic efficiency of 42 World and East Asia countries and years 1996–2006. They apply DEA window analysis and panel data techniques and find an inverted U-shaped relationship among electricity generation and countries' economic efficiency.

3. Data and methodology

This paper uses data for a sample of 78 firms operating in the Greek renewable energy sector[2] as provided by ICAP [51][3] for the period 2006–2008. In our DEA context we use three inputs and four outputs in order to measure the financial performance of the firms into consideration. The three inputs have been used in order to capture firms' capital structure, operating activity and liquidity levels[4]. Namely, these are: debt to equity (debt/equity), assets turnover (turnover/average assets) and current ratio (average current assets/average short-term debt). In addition four outputs are used in order to capture firms' profitability levels. These are: gross profit margin (gross profits/turnover (%)), operating profit margin (operating profits/turnover (%)), return on equity (pre tax profits/average equity (%)) and return on assets (Pre tax profits/Average assets (%)).

Table 1 presents the descriptive statistics (mean vales and standard deviations) of the variables used in our DEA formulation. It appears that there are a lot of fluctuations of the variables used for the time period of our study. This can be viewed especially when looking at the standard deviations values over the years for gross and operating profit margins. It appears that the Greek renewable energy sector consists of firms with different performance levels indicating high levels of competitiveness.

Based on the work by Koopmans [55] and Debreu [56] the production set Ψ constraints the production process and is the set of physically attainable points (x, y):

$$\Psi = \left\{ (x, y) \in \Re_{+}^{N+M} \middle| x \text{ can produce } y \right\} \tag{1}$$

where $x \in \Re_{+}^{N}$ is the input vector and $y \in \Re_{+}^{M}$ is the output vector. As suggested by several authors [57,58], Hoffman's [59] discussion

[2] According to ICAP the firms of our sample consist the population of the firms operating in the Greek renewable energy sector. Mainly firms operate on wind and hydropower energy, whereas the minority of them on solar energy production.

[3] ICAP directory provides financial data which are based on the published accounts of the entire Ltd. and Plc. firms operating in Greece.

[4] In order to deal with negative values we applied the translation invariance property of the variable returns to scale (VRS) models [52–54].

Table 1
Descriptive statistics of the inputs/outputs used for the period 2006–2008.

		Debt/equity ratio	Current ratio	Assets turnover ratio
Inputs				
2006	Mean	1.912	2.765	0.178
2006	Std	2.418	5.528	0.151
2007	Mean	2.657	3.622	0.167
2007	Std	6.657	7.096	0.127
2008	Mean	3.236	3.382	0.186
2008	Std	9.303	4.987	0.136

		ROE	ROA	Gross profit margin	Margin
Outputs					
2006	Mean	5.317	1.634	41.713	7.296
2006	Std	27.094	23.568	29.017	47.886
2007	Mean	7.783	4.596	37.632	5.260
2007	Std	21.721	7.734	32.961	55.341
2008	Mean	7.180	5.350	41.124	11.485
2008	Std	24.369	7.820	33.151	46.327

regarding Farrell's [60] paper was the first to indicate that linear programming can be used in order to find the frontier and estimate efficiency scores, but only for the single output case. Later, Boles [61,62] developed the formal linear programming problem with multiple outputs identical to the constant returns to scale (CRS) model in Charnes et al. [63] who named the technique as Data Envelopment Analysis (DEA). Later Banker et al. [64] used convex hull of $\hat{\Psi}_{FDH}$ [65] to estimate Ψ and thus to allow for variable returns to scale (VRS) as:

$$\hat{\Psi}_{VRS} = \left\{ (x,y) \in \Re^{N+M} | y \leq \sum_{i=1}^{n} \gamma_i y_i; x \geq \sum_{i=1}^{n} \gamma_i x_i \text{ for } (\gamma_1, \ldots, \gamma_n) \right. \\ \left. \text{such that} \sum_{i=1}^{n} \gamma_i = 1; \gamma_i \geq 0, i = 1, \ldots, n \right\} \quad (2)$$

This paper uses an output oriented model implying that firms try to keep constant their levels of inputs whereas simultaneously they try to maximize their outputs i.e.:

$$\hat{\lambda}_{VRS}(x,y) = \sup\{\lambda | (x, \lambda y) \in \hat{\Psi}_{VRS}\} \quad (3)$$

which then can be computing by solving the following linear program:

$$\hat{\lambda}_{VRS} = \sup \left\{ \lambda | \lambda y \leq \sum_{i=1}^{n} \gamma_i y_i; x \geq \sum_{i=1}^{n} \gamma_i x_i \text{ for } (\gamma_1, \ldots, \gamma_n) \right. \\ \left. \text{such that} \sum_{i=1}^{n} \gamma_i = 1; \gamma_i \geq 0, i = 1, \ldots, n \right\} \quad (4)$$

Simar and Wilson [66–68] suggest that DEA estimators were shown to be biased by construction. They introduced an approach based on bootstrap techniques [69] to correct and estimate the bias of the DEA efficiency indicators. The main applications of bootstrap techniques can be found in the work of Simar and Wilson [66,67] for bias correction and construction of confidence intervals of the efficiency estimator, for test procedures assessing returns to scale [70] and for application to Malmquist indices [71].

The bootstrap bias estimate for the original DEA estimator $\hat{\theta}_{VRS}(x,y)$ can be calculated as:

$$\widehat{BIAS}_B(\hat{\lambda}_{VRS}(x,y)) = B^{-1} \sum_{b=1}^{B} \hat{\lambda}^*_{VRS,b}(x,y) - \hat{\lambda}_{VRS}(x,y) \quad (5)$$

Furthermore, $\hat{\lambda}^*_{VRS,b}(x,y)$ are the bootstrap values and B is the number of bootstrap replications. Then a bias corrected estimator of $\lambda(x,y)$ can be calculated as:

$$\hat{\hat{\lambda}}_{VRS}(x,y) = \hat{\lambda}_{VRS}(x,y) - \widehat{BIAS}_B(\hat{\lambda}_{VRS}(x,y)) = 2\hat{\lambda}_{VRS}(x,y) \\ - B^{-1} \sum_{b=1}^{B} \hat{\lambda}^*_{VRS,b}(x,y) \quad (6)$$

In order to implement the homogenous bootstrap algorithm for a set of bootstrap estimates $\{\hat{\lambda}^*_b(x,y) | b = 1, \ldots, B\}$ for a given fixed point (x, y) the following eight steps must be carried out:

1. From the original data set we compute $\hat{\lambda}_{VRS}$.
2. Then we apply the "rule of thump" [72, pp. 47–48] to obtain the bandwidth parameter h.
3. We generate $\beta^*_1, \ldots, \beta^*_n$ by drawing with replacement from the set $\{\hat{\lambda}_1, \ldots, \hat{\lambda}_n, (2 - \hat{\lambda}_1), \ldots, (2 - \hat{\lambda}_n)\}$.
4. Then we draw $\varepsilon^*_i, i = 1, \ldots, n$ independently from the kernel function $K(.)$ and compute $\beta^{**}_i = \beta^*_i + h\varepsilon^*_i$ for each $i = 1, \ldots, n$.
5. For each $i = 1, \ldots, n$ we compute β^{***}_i as: $\beta^{***}_i = \bar{\beta}^* + (\beta^{**}_i - \bar{\beta}^*/(1 + h^2\sigma^2_k\sigma^2_\beta)^{1/2})$, where $\bar{\beta}^* = \sum_{i=1}^{n} \beta^*_i/n$, $\sigma^2_\beta = \sum_{i=1}^{n} (\beta^*_i - \bar{\beta}^*)/n$ and σ^2_k is the variance of the probability density function used for the kernel function. In addition λ^*_i can then be computed as: $\lambda^*_i = \begin{cases} 2 - \beta^{***}_i \forall \beta^{***}_i < 1 \\ \beta^{***}_i \text{ otherwise} \end{cases}$.
6. The bootstrap sample is created as: $X^*_n = \{(x^*_i, y_i) | i = 1, \ldots, n\}$ where $x^*_i = \lambda^*_i \hat{x}^\partial(y_i) = \lambda^*_i \hat{\lambda}^{-1}_i x_i$.
7. We compute the DEA efficiency estimates $\hat{\lambda}^*_i(x_i, y_i)$ for each of the original sample observations using the reference set X^*_n in order to obtain a set of bootstrap estimates.
8. Finally, we repeat steps 3–7 B times (at least 2000 times) to obtain a set of bootstrap estimates $\left\{\hat{\lambda}^*_b(x,y) \middle| b = 1, \ldots, B\right\}$.

In addition this paper constructs estimates of stochastic kernels and in order to identify how the inputs/outputs used in our study have affected the financial performance of the firms over the three year periods of our study. Following, Racine [73] let $f(.)$ and $\mu(.)$ be the joint and marginal densities of (X, Y) and X respectively. Let Y and X be the dependent and independent variables accordingly.

Table 2
Bias corrected results, rankings and efficiency changes of firms' performance over the three years.

Rankings	Company names	VRS_{BC} 06	VRS_{BC} 07	VRS_{BC} 08	Average	% Change
1	Iweco Xonos Lasithiou Kritis A.E.&B.E.	0.98346	0.96443	0.95967	0.96919	−2.41863
2	Aiolika Parka Moiron A.E.	0.98166	0.96857	0.95722	0.96915	−2.48995
3	Terpandros Aiolika Parka A.E.	0.98438	0.94812	0.94629	0.95959	−3.86982
4	Aioliki Karistou A.E.	0.94976	0.97042	0.95724	0.95914	0.78767
5	Terna Energiaki Evrou A.E.	0.97913	0.96239	0.92806	0.95653	−5.21557
6	Myhs Thermorema A.E.	0.97119	0.94870	0.94860	0.95616	−2.32603
7	Aioliki Antissas A.E.	0.97921	0.94760	0.93925	0.95535	−4.08014
8	Aioliki Sidirokastrou A.E.	0.96808	0.94210	0.93541	0.94853	−3.37480
9	Aiolika Parka Axladion A.E.	0.97400	0.94309	0.92842	0.94850	−4.67939
10	Enteka Aiolika Parka A.E.	0.97762	0.92752	0.93765	0.94760	−4.08847
11	Myhe Kerasovou A.E.	0.97046	0.94072	0.92503	0.94540	−4.68157
12	Elliniki Texnodromiki Anemos A.E.	0.97775	0.93998	0.91052	0.94275	−6.87576
13	Rokas Aioliki A.B.E.E.	0.97651	0.91168	0.93935	0.94251	−3.80474
14	Ipeirotiki Energiaki A.E.	0.96605	0.92529	0.93537	0.94224	−3.17611
15	Energiaki Servouniou A.E.	0.96940	0.89979	0.95189	0.94036	−1.80638
16	Energi E2 Aioliki A	0.97453	0.90896	0.92729	0.93693	−4.84666
17	Aiolika Parka Krion A.E.	0.98528	0.90125	0.91779	0.93477	−6.85010
18	Anemoessa Aiolika Parka A.E.	0.97702	0.93286	0.89054	0.93347	−8.85140
19	Lamkos Energiaki A.E.	0.97257	0.90809	0.91633	0.93233	−5.78213
20	Rokas Aioliki Evoia A.B.&E.E.	0.97970	0.88690	0.92837	0.93166	−5.23886
21	Zefyros E.P.E.	0.97887	0.89598	0.91675	0.93053	−6.34595
22	Panagitsa A.E.	0.98243	0.90982	0.89661	0.92962	−8.73551
23	Aioliki Didimon A.E.	0.94614	0.90170	0.93971	0.92919	−0.67951
24	Terna Energiaki A.B.E.T.E.	0.92873	0.91789	0.93766	0.92809	0.96139
25	Aiolika Parka Arkadias A.E.	0.96669	0.89459	0.92075	0.92734	−4.75210
26	Fotoenergia Sidirokastrou A.E.	0.98612	0.90367	0.89154	0.92711	−9.59070
27	Energiako Diktio E.P.E.	0.96845	0.88545	0.91998	0.92463	−5.00555
28	Rokas Aioliki Kriti A.E.	0.98141	0.87645	0.90983	0.92257	−7.29383
29	Bioaerio Energias Ano Liosia A.E.	0.96583	0.88905	0.91265	0.92251	−5.50626
30	Katharo Energiaki A.E.	0.97899	0.86681	0.91743	0.92108	−6.28856
31	Idroelektriki Achaias A.E.	0.97584	0.92856	0.85836	0.92092	−12.03835
32	Rokas Aioliki ZARAKES A.B.$E.E.	0.97199	0.89384	0.89286	0.91956	−8.14084
33	Pindos Energiaki A.E.	0.96637	0.86898	0.92289	0.91941	−4.49971
34	Aioliki Kykladon A.E.	0.96880	0.89595	0.88339	0.91605	−8.81561
35	Arkadika Meltemia A.E.	0.96882	0.90287	0.87532	0.91567	−9.65155
36	Aiolika Parka Thrakis A.E.	0.94729	0.87344	0.91821	0.91298	−3.06964
37	Energi E2 Aiolika Parka Karistias A.E.	0.97202	0.88426	0.88100	0.91243	−9.36394
38	Vector Aiolika Parka Elldas A.E.	0.95202	0.86844	0.90358	0.90801	−5.08812
39	Kigkori Bathipedo Energiaki-Texniki A.E.	0.96827	0.87101	0.87978	0.90635	−9.13914
40	Diethnis Aioliki A.T.E.&B.E.	0.97650	0.85260	0.88446	0.90452	−9.42483
41	ΔEH Ananeosimes-Rokas A.B.&E.E.	0.97389	0.85126	0.88733	0.90416	−8.88818
42	Wre Hellas A.E.	0.96403	0.87032	0.87710	0.90381	−9.01721
43	Rokas Aioliki Thraki II A.B.E.E.	0.97904	0.85338	0.87770	0.90337	−10.35054
44	Aioliki Karpastoniou A.E.	0.93865	0.86402	0.90699	0.90322	−3.37314
45	Nanko Energia A.B.E.&T.E.	0.97489	0.85208	0.88041	0.90246	−9.69128
46	Sperxios A.E.	0.96208	0.86500	0.87845	0.90184	−8.69275
47	ΔEH Ananeosimes-Mek Energiaki Boreino Pellis A.E.	0.97630	0.87732	0.84927	0.90096	−13.01118
48	Rokas Aioliki Thraki A.B.E.E.	0.97290	0.85116	0.87461	0.89956	−10.10291
49	Sunergy A.E.	0.97882	0.83943	0.87879	0.89902	−10.21888
50	Evroenergiaki A.E.	0.96960	0.85828	0.86771	0.89853	−10.50877
51	Idroelektrikos Stathmos Oinousas Serron A.E.	0.96552	0.77469	0.94547	0.89523	−2.07755
52	Idroelektriki Evritanias A.E.	0.95428	0.88957	0.83943	0.89442	−12.03496
53	Aioliki Panaxaikou A.E.	0.96929	0.86003	0.85242	0.89391	−12.05686
54	Idrodinamiki Energeiaki A.E.	0.93986	0.83783	0.88821	0.88863	−5.49634
55	Elliniki Energikontor A.E.	0.97017	0.80078	0.89273	0.88789	−7.98192
56	Iweco Megali Brisi Irakleiou A.E.B.E.	0.93812	0.93134	0.79315	0.88754	−15.45334
57	Idroelektriki A.E.	0.93527	0.85417	0.86780	0.88575	−7.21453
58	Gkamesa Energiaki Hellas A.E.	0.88918	0.84364	0.91664	0.88316	3.08868
59	Diethnis Aioliki Thrakis A.E.	0.94212	0.81051	0.88813	0.88026	−5.73102
60	Ilektron A.E.	0.94205	0.93625	0.75715	0.87849	−19.62788
61	ΔEH Ananeosimes A.E.	0.90405	0.91419	0.81704	0.87843	−9.62451
62	Nioy Baserkraft A.E.	0.94439	0.74713	0.93988	0.87713	−0.47731
63	Polipotamos Aioliki Energia A.E.	0.94589	0.87656	0.80110	0.87451	−15.30731
64	Texniki Energeiaki A.E.	0.97038	0.81175	0.84074	0.87429	−13.35982
65	Kerkinis Y.H.S.&A.E.	0.96808	0.76368	0.86513	0.86563	−10.63507
66	Aigeoilektriki Stavrou Elikonos A.E.	0.88371	0.83425	0.87036	0.86277	−1.51149
67	Aiolika Parka Kikladon-Mpourlari A.B.&E.E.	0.94187	0.78974	0.81546	0.84903	−13.42140
68	Ilektron Energiaki A.E.	0.94091	0.80284	0.78495	0.84290	−16.57551
69	Idroenergiaki A.E.	0.93191	0.78470	0.79450	0.83704	−14.74565
70	Aioliki Hellas A.E.	0.96502	0.77800	0.75434	0.83245	−21.83156
71	Idor Kataskeyastiki A.E.	0.95198	0.69207	0.81200	0.81869	−14.70370
72	Aioliki Energiaki Peloponisou A.E.	0.97692	0.64524	0.73896	0.78704	−24.35870
73	Idroenergiaki Ellados A.E.	0.97232	0.62640	0.73232	0.77701	−24.68312
74	Amiantit m.yh.s. Kastaniotiko A.E.	0.96732	0.70684	0.57386	0.74934	−40.67533
75	Fdiotiki Energiaki A.E.	0.97907	0.61839	0.62252	0.73999	−36.41772
76	Idroxoos Energiaki A.E.	0.95963	0.58425	0.66375	0.73588	−30.83308

Table 2 (*Continued*)

Rankings	Company names	VRS_{BC} 06	VRS_{BC} 07	VRS_{BC} 08	Average	% Change
77	MELTEMIMEΛTEMI-KASTPI A.B.E.& T.E.	0.93639	0.62562	0.60156	0.72119	−35.75792
78	Kallisti Energiaki A.E.	0.76388	0.64384	0.64137	0.68303	−16.03834
	Mean	0.96012	0.85675	0.86965	0.89550	−9.42994
	Standard deviation	0.03041	0.08886	0.08437	0.05871	8.27556
	Minimum	0.76388	0.58425	0.57386	0.68303	−40.67533
	Maximum	0.98612	0.97042	0.95967	0.96919	3.08868

Then the stochastic kernel (or the conditional distribution function) can be estimated as:

$$\hat{g}(y|x) = \frac{\hat{f}(x, y)}{\hat{f}(x)} \tag{7}$$

Using a product Gaussian kernel the $\hat{f}(x, y)$ can be estimated as:

$$\hat{f}(x, y) = \frac{1}{n}\sum_{i=1}^{n} \frac{1}{h_x\sqrt{2\pi}} e^{-0.5\left(\frac{x-x_i}{h_x}\right)^2} \frac{1}{h_y\sqrt{2\pi}} e^{-0.5\left(\frac{y-y_i}{h_y}\right)^2} \tag{8}$$

and $\hat{f}(x)$ as:

$$\hat{f}(x) = \frac{1}{n}\sum_{i=1}^{n} \frac{1}{h_x\sqrt{2\pi}} e^{-0.5\left(\frac{x-x_i}{h_x}\right)^2} \tag{9}$$

where (h_x, h_y) are representing the bandwidths calculated by the least squares cross-validation data driven method as suggested by Hall et al. [74].

4. Empirical results

Following the methodology analyzed so far, Table 2 presents the results obtained after correcting firms' efficiency scores from bias.[5] Looking at the average efficiency values over the three years time period we can realize that 47 firms out of 78 have efficiency scores greater than 0.9 (the value of 1 indicates that the firm is efficient). The minimum average bias corrected efficiency score is 0.68 and the maximum average bias corrected efficiency score is 0.96. The standard deviation of the average bias corrected efficiency values is only 0.05. This value of standard deviation indicates that the Greek renewable sector is a high competitive sector with firms operating more ore less in similar efficiency levels.

During the period of our study (looking at the average efficiency values) the ten firms with the highest efficiency scores are reported to be: Iweco Xonos Lasithiou Kritis A.E.&B.E., Aiolika Parka Moiron A.E., Terpandros Aiolika Parka A.E., Aioliki Karistou A.E., Terna Energiaki Evrou A.E., Myhs Thermorema A.E., Aioliki Antissas A.E., Aioliki Sidirokastrou A.E., Aiolika Parka Axladion A.E. and Enteka Aiolika Parka A.E. Similarly, the 10 firms with the lowest performances are reported to be: Idroenergiaki A.E., Aioliki Hellas A.E., Idor Kataskeyastiki A.E., Aioliki Energiaki Peloponisou A.E., Idroenergiaki Ellados A.E., Amiantit M.YH.S. Kastaniotiko A.E., Fdiotiki Energiaki A.E., Idroxoos Energiaki A.E., Meltemi-Kastri A.B.E.&T.E. and Kallisti Energiaki A.E.

One noticeable characteristic of the firms is that the majority of the higher performers are specialized on wind energy whereas the majority of the lower performers on hydropower energy. Another point that needs to be raised is that the standard deviation values of the top ten and last 10 performers are 0.007 and 0.055 respectively indicating a high competitive market. When examining the percentage changes of the bias corrected efficiency scores (% Change) it is realized that only three firms reported efficiency gains over the years. These are: Gkamesa Energiaki Hellas A.E. (3.08%), Terna Energiaki A.B.E.T.E. (0.96%) and Aioliki Karistou A.E. (0.78%). The rest of the firms report negative percentage values of efficiency changes with the 10 firms with the highest negative efficiency changes to be: Kallisti Energiaki A.E. (−16.03%), Ilektron Energiaki A.E. (−16.57%), Ilektron A.E. (−19.62%), Aioliki Hellas A.E. (−21.83%), Aioliki Energiaki Peloponisou A.E. (−24.35%), Idroenergiaki Ellados A.E. (−24.68%), Idroxoos Energiaki A.E. (−30.83%), Meltemiμελτεμι-Καστρι A.B.E.&T.E. (−35.75%), Fdiotiki Energiaki A.E. (−36.41%) and Amiantit M.YH.S. Kastaniotiko A.E. (−40.67%).

In order to examine the influence of the average values (over the three year period) of financial ratios on the average value of the efficiency scores obtained the conditional density figures have been extracted. Fig. 1 indicates the stochastic kernels of gross profit margin (AVGPM – Fig. 1a), operating profit margin (AVOM – Fig. 1b), ROA (AVROA – Fig. 1c), ROE (AVROE – Fig. 1d), current ratio (AVCR – Fig. 1e), assets turnover ratio (AVATR – Fig. 1f) debt/equity ratio (AVDER – Fig. 1g) against firms' average efficiency levels (AVEFF). In order to understand the figures a fixed point can be chosen on the axis labeled AVEFF. Then, by slicing the graph from this point and moving parallel for instance to AVGPM axis (Fig. 1a), the estimated distribution of firms' average efficiencies levels over the examined time period conditional on average gross profit margin levels can be traced [75, p. 452].

Looking at Fig. 1a the conditional density has several distinctive peaks. It appears that equally positive and negative levels of firms' gross profit margin can result on higher efficiency scores. In addition it is more likely that lower levels of gross profit margin can result on lower efficiency levels. Similarly in Fig. 1b positive and negative levels of operating profit margin can result to firms' higher efficiency levels, whereas values of less than −50% of operating profit margin lead firms to lower financial efficiency levels. More clearly for Fig. 1c and d positive values of ROA and ROE lead to higher efficiency levels, whereas lower ROA and ROE values to lower efficiency gains.

When looking at Fig. 1e and f it can be realized that the majority of firms has higher efficiency levels regardless the levels of assets turnover ratio and debt/equity ratio. Finally, when looking at Fig. 1g firms with higher debt/equity ratio tend to have lower efficiency levels with more than 30% AVDER indicating a 0.7–0.75 efficiency level, 20–30% of AVDER indicating 0.75–0.85 efficiency level, 20–10% of AVDER indicating 0.85–0.95 efficiency level and less than 10% AVDER indicating more than 0.9 efficiency level.

In addition to Fig. 1, Fig. 2 provides a kernel conditional density estimate using local polynomial estimation [76–78] of firms' average efficiency estimates against the time period. In such a way the stochastic kernel provide as with the visualization of the effect of the time period on firms' efficiency scores (in average terms). As can be seen, moving along the time period started from 2006 to 2008 the firms' efficiency levels are decreasing. This maybe can be attributed to the fact that 2007 the financial crisis was started and in that respect firms' finances may have been affected directly or indirectly having as a result an immediate impact on their efficiency levels.

[5] Due to the enormous results obtained over the three year period, the original efficiency scores, the bias, the standard deviation values of bias and the 95% confidence interval of the biased corrected efficiency estimates are available upon request.

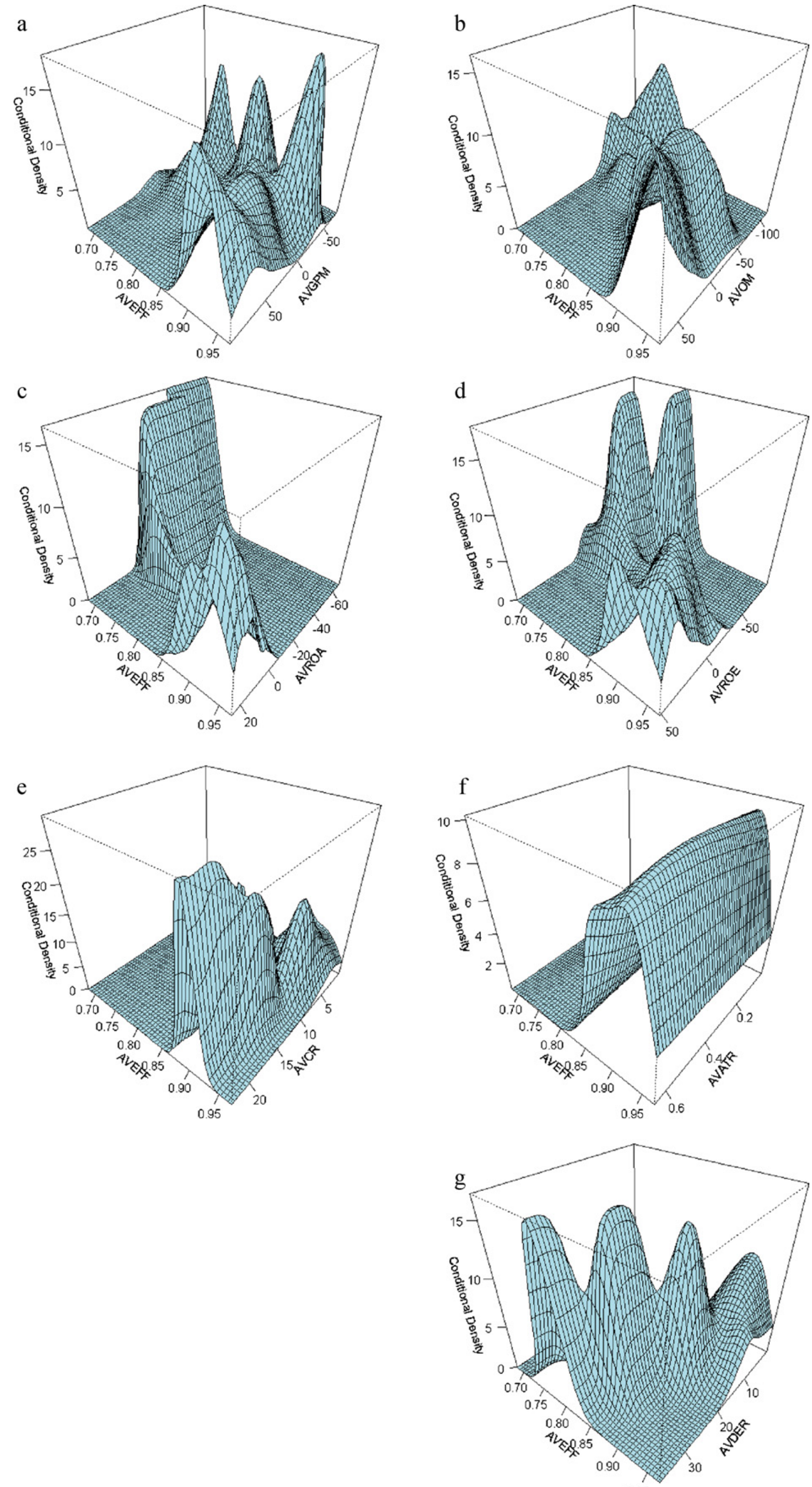


Fig. 1. Stochastic kernels of the average bias corrected efficiency scores and the inputs/outputs used for 2006–2008.

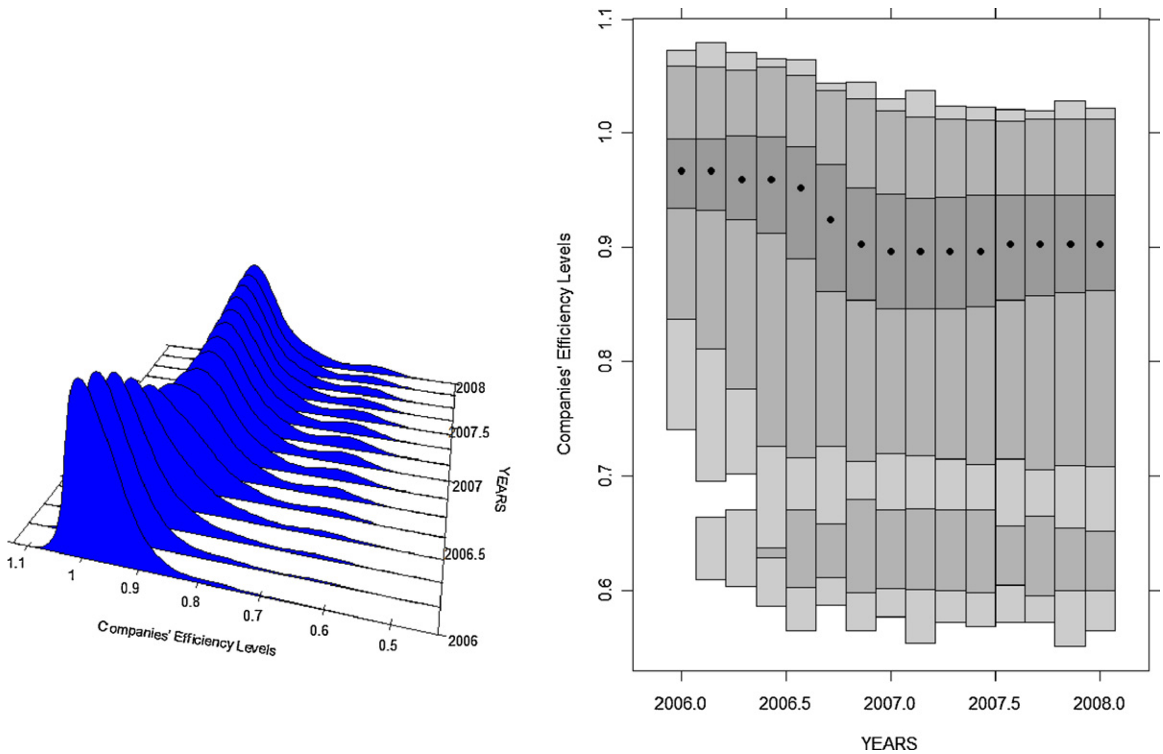


Fig. 2. A stochastic kernel of the average bias corrected efficiency scores and the time period 2006–2008.

5. Conclusion

The solution to environmental problems requires long-term actions that lead to sustainable development. The use of renewable energy resources seem to be the most efficient and effective way of tackling and coping with environmental degradation.

This paper analyses the Greek renewable energy sector by applying a DEA bootstrap formulation based on financial data for 78 firms for 2006–2008. The empirical results indicate that:

- Firms operating on wind energy sector tend to have a higher financial efficiency than the ones operating on hydropower energy.
- The efficiency levels of firms operating in the Greek renewable sector are of similar levels implying that the Greek renewable sector is a high competitive one.
- The firms' financial performance has been mainly influenced by their higher level of ROA, ROE and from their lower levels of debt/equity ratio.

It appears that the majority of the firms operating in the Greek renewable sector are based on the production of wind energy. However, it is our feeling that the Greek government and public policy makers must also orient their policies towards the enhancement or "opening" of the solar energy market. In addition given the huge technical potential of solar energy technologies several problems which are related to financial, regulatory and institutional barriers [79] need to be overcame in order for the Greek firms to invest in large scale projects.

According to several authors [80,81] solar energy has several advantages being the cleanest energy resource that does not compromise or add to the global warming. Solar energy can be exploited through the solar thermal and solar photovoltaic (PV) routes for various applications and appear to be one of the best renewable energy source [82]. According to Zahedi [83] the amount of energy received in 1 h by the earth from the sun is equivalent to world energy consumption in one year.

In any case, sustainable development is closely related to renewable energy sources and their utilization. The attainment of sustainability demands the exploration of sustainable energy resources, the development and use of renewable energy technologies, the development of R&D and the transfer of technologies.

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